



## Parabolic Trough Receiver Testing

### Thermal Loss Tests

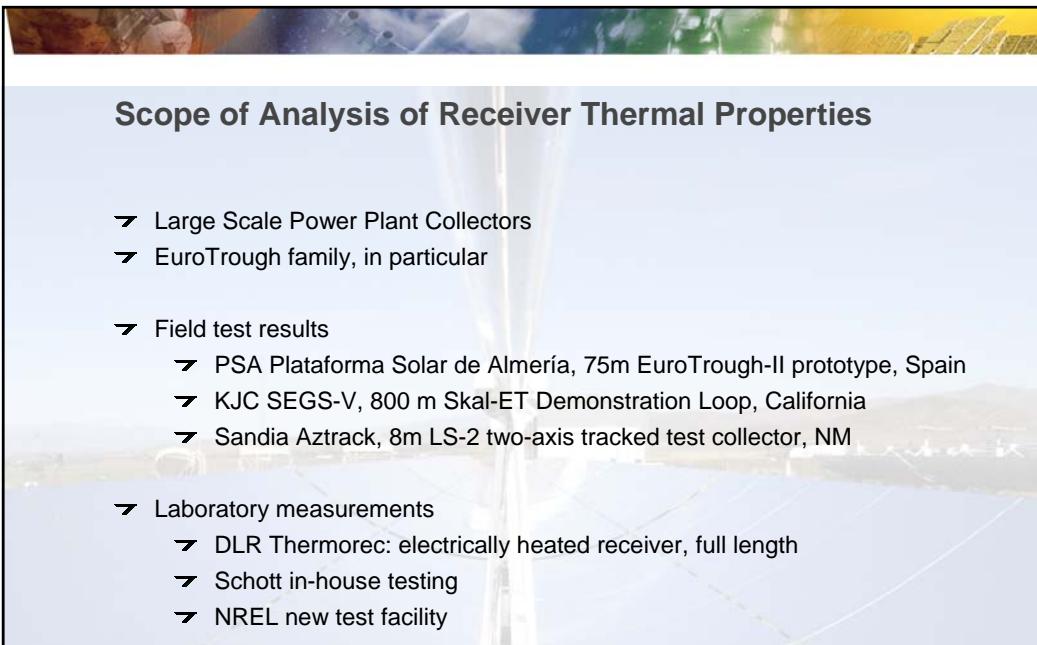
Workshop Lake Tahoe, February 13<sup>th</sup>, 2006

Eckhard Lüpfert

German Aerospace Center DLR (Cologne/Almería)



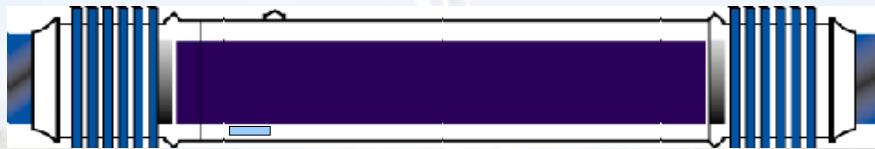
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## Scope of Analysis of Receiver Thermal Properties

- Large Scale Power Plant Collectors
- EuroTrough family, in particular
- Field test results
  - PSA Plataforma Solar de Almería, 75m EuroTrough-II prototype, Spain
  - KJC SEGS-V, 800 m Skal-ET Demonstration Loop, California
  - Sandia Aztrack, 8m LS-2 two-axis tracked test collector, NM
- Laboratory measurements
  - DLR Thermorec: electrically heated receiver, full length
  - Schott in-house testing
  - NREL new test facility

## Scheme: Parabolic Trough Receiver (Heat Collecting Element)



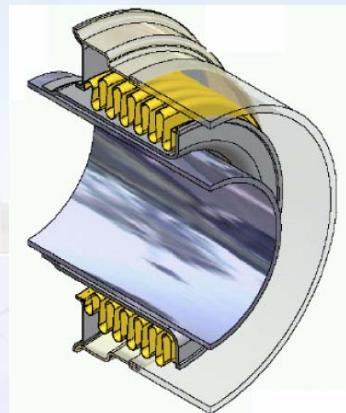
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## Schott PTR70



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## How to measure thermal losses of receivers (1)

- ☛ thermal equilibrium, steady state
  - ☛ heat inside with constant power, measure equilibrium temperature
  - ☛ end losses: insulated, or active temperature barrier (adiabatic)
    - ☛ DLR Thermorec; NREL; Schott; Ciemat
- ☛ thermal equilibrium, quasi steady state
  - ☛ heat transfer fluid flow, constant inlet temperature, constant mass flow measure outlet temperature, calculate enthalpy difference
    - ☛ PSA; Sandia (Aztrack); KJC (Flagsol)
- ☛ no solar radiation on receiver
- ☛ with radiation on receiver (when irradiance and optical efficiency are known)

## How to measure thermal losses of receivers (2)

- ☛ measure emissivity, conductivity
  - ☛ establish physical models (radiation from absorber)
  - ☛ what about bellows and supports?
- ☛ measure glass envelope temperature
  - ☛ calculate heat convection (from glass envelope to environment)
  - ☛ what wind speed?
- ☛ numerical models, energy balance
  - ☛ EES (Forristall)
  - ☛ many others...
  - ☛ including radiation, conduction, convection



## Issues

- ☛ Stability of coating
  - ☛ responsible for radiative losses
- ☛ Stability of vacuum
  - ☛ responsible for conduction/convection losses
- ☛ Supports
  - ☛ conduction losses



## Test facilities

- ☛ DLR
- ☛ PSA
- ☛ KJC/SkalET
- ☛ Sandia



## Thermal loss testing (DLR, Thermorec)



## EuroTrough at Plataforma Solar de Almería





## Aztrack (Sandia)



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## EuroTrough/SkalET Demonstration at KJC, California



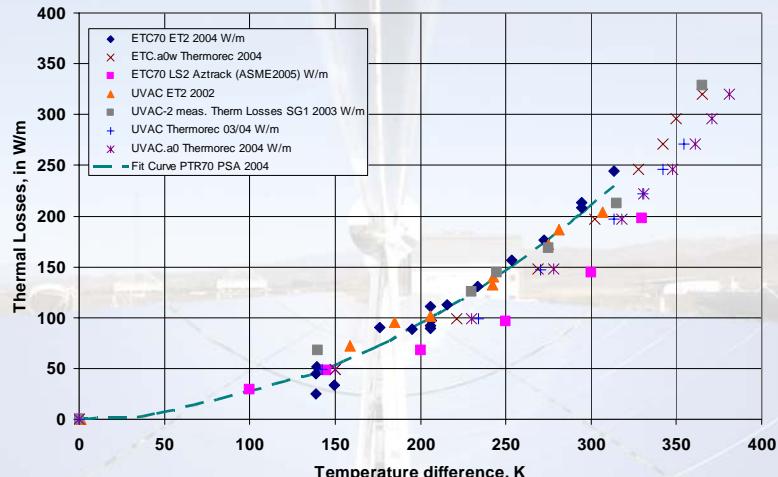
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## Thermal Data Comparison Parabolic Trough Receivers



## Definitions and Nomenclature, Examples

- Collector reference **aperture area** (net, gross, nominal)
- peak optical **efficiency**  $\eta_{0,\text{peak}}$
- **Irradiance** onto the collector aperture G
- Specular reflectance  $\rho_s$
- **attenuation properties**: transmittance, emittance, cleanliness, ...
- **geometric properties**: gaps, end losses, shading
- angle of incidence (from aperture normal)  $\theta$
- **incidence angle modifier** functions (IAM)  $\kappa$
- intercept factor  $\gamma$
- reduced mean temperature difference  $T_m = (T_m - T_a)/G$

## Collector model for test evaluation - equations

- $P_{\text{coll}} = P_{\text{abs}} - P_{\text{th,loss}}$
- $P_{\text{th,loss}} = A_{\text{net}} K(T) (T_{\text{abs}} - T_a)$  **with heat transfer coefficient:**  $K(T) = K_0 + K_1 (T_{\text{abs}} - T_a)$
- $P_{\text{th,loss}} \approx \varepsilon \sigma_{\text{Boltzmann}} A_{\text{abs}} (T_{\text{abs}}^4 - T_a^4) + K_{\text{edge}}^* (T_{\text{abs}} - T_a)$
- $P_{\text{abs}} = G_b \cdot A_{\text{net}} \cdot \eta_0$
- $\eta_0(\theta) = \eta_{\text{opt,refl}}(\theta) \cdot \eta_{\text{geo,refl}}(\theta) \cdot \gamma(\theta, \sigma) \cdot \eta_{\text{opt,rec}}(\theta) \cdot \eta_{\text{geo,rec}}(\theta)$

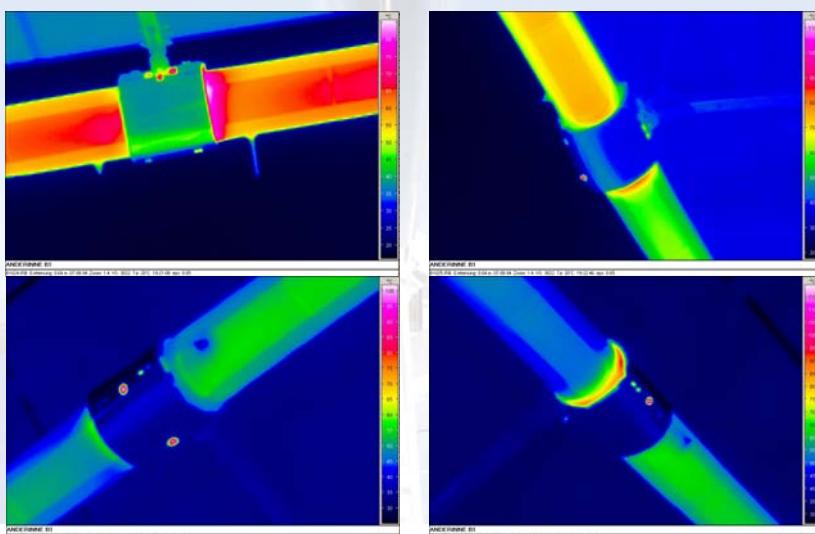
$$\frac{P_{\text{coll}}}{A_{\text{net}} G_b} = \eta_{\text{coll}} = F' \eta_0 - F' K(T) \cdot \frac{T_m - T_a}{G_b}$$

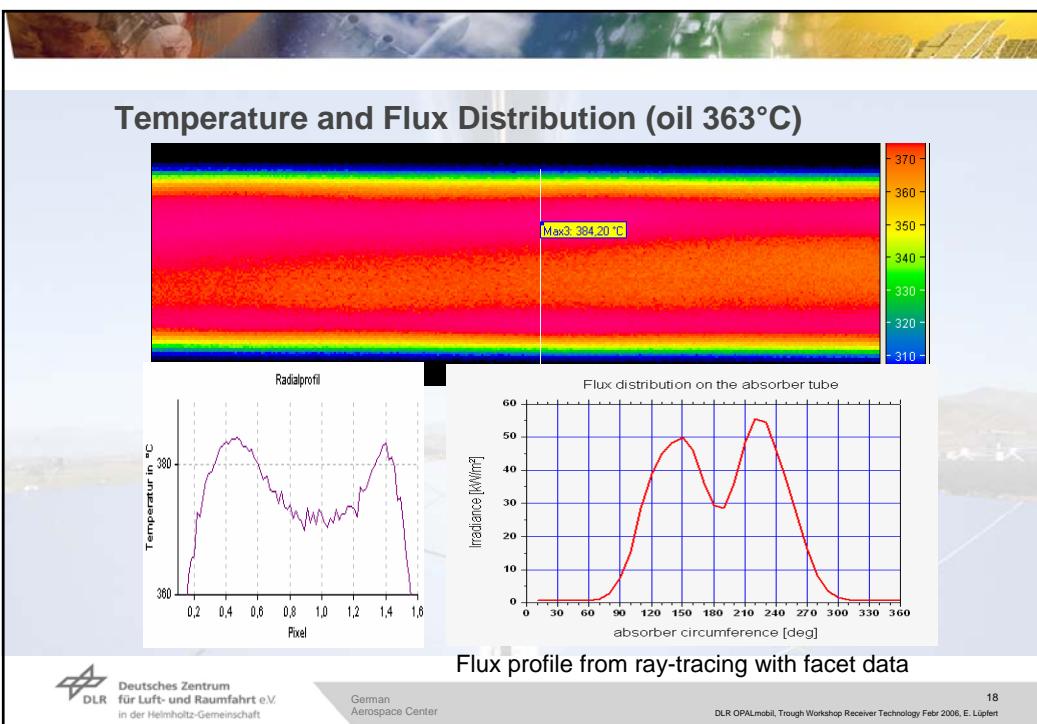
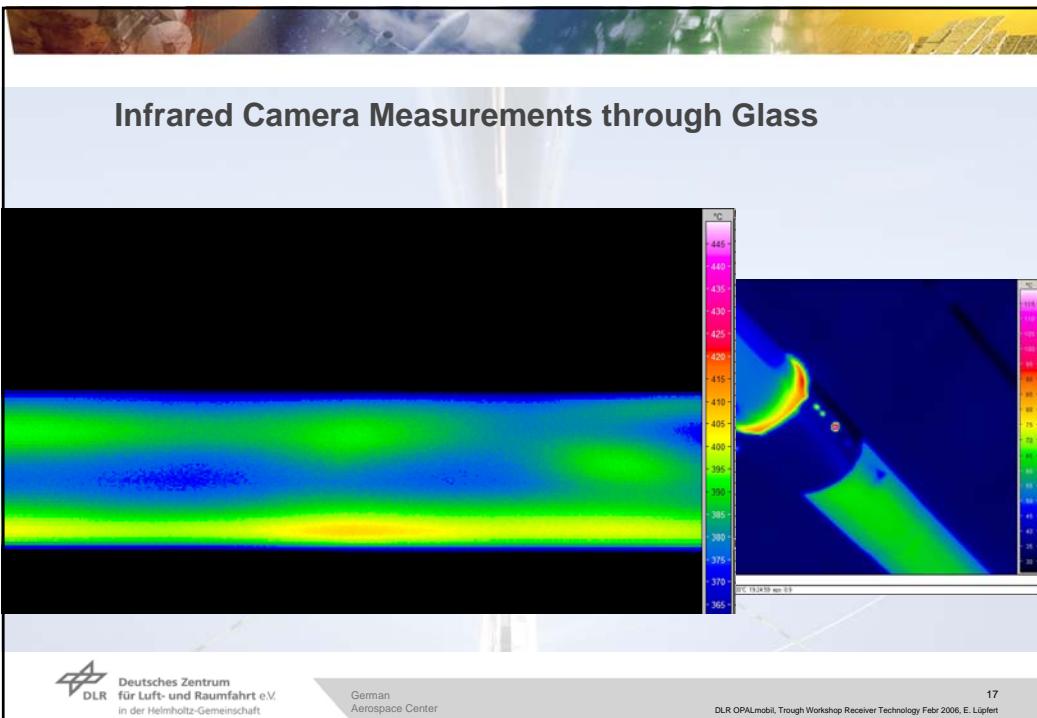
$$\frac{P_{\text{coll}}}{A_{\text{net}}} = F' \cdot \eta_0 \cdot G_b + F' \cdot \eta_{\text{opt,rec}} \cdot \psi_{\text{rec}} \cdot \frac{G_d}{C_{\text{geo}}} - F' K_0 \cdot (T_m - T_a) - F' K_1 \cdot (T_m - T_a)^2$$

$$- F' c_{\text{Wind}} v_{\text{wind}} \cdot (T_m - T_a) - K_{\text{pip}} \frac{l_{\text{pip}} \pi d_{\text{pip}}}{A_{\text{net}}} (T_m - T_a)$$

$$\eta = \eta_0' - c_1' T_m^* - c_2' G_b T_m^{*2} - c_3' G_b^2 T_m^{*3}$$

## Infrared Camera Measurements on Glass Surface





## References

- ☛ Tim Moss, Douglas Brosseau, Performance Testing of the New Schott Trough Receiver, ASME ISEC Orlando 2005, Paper No. 76022
- ☛ Eckhard Lüpfer, Klaus Pottler, Klaus-Jürgen Riffelmann, Steffen Ulmer, Björn Schiricke, Andreas Neumann: Parabolic Trough Analysis Techniques for Optical Performance. J. Sol. En. Eng., 2006, and ASME ISEC, August 6-12, 2005, Orlando, Florida, No. ISEC2005-76023
- ☛ Pfänder M., Lüpfer E., Heller P.: Pyrometric Temperature Measurement on Solar Thermal Receivers. J. Sol. En. Eng. 2006, Paper No. SOL-05-1078
- ☛ Project Reports Parfor (DLR/Schott internal)
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